FORECASTING GUIDE FOR TROPICAL CYCLONES CROSSING TAIWAN

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The Central Mountain Range (CMR) of Taiwan is a major influence on the track and intensity of tropical cyclones that cross or nearly cross the island. The CMR is oriented approximately from north to south for over 100 n mi. with terrain above 6000 ft, and with many peaks over 10000 ft high (Brand and Blelloch, 1973). Due to its significance, a number of papers have been written over the years on the effect the CMR has on tropical cyclones. This forecast guide is a combination of excerpts of several of these papers and climatology of tropical cyclones crossing Taiwan.

This guide for forecasting tropical cyclone crossing Taiwan has two parts to it. The first is a climatology study using the Macintosh IIx computer at Det 1, 1WW. A tropical cyclone database has been compiled by Det 1 which can be process and displayed on the Macintosh IIx. The climatology study done updates a study done by Brand and Blelloch (1973). This first part looks at the intensity and speed changes associated with typhoons crossing Taiwan. The second part is a guide to forecasting tropical cyclone motion for storms crossing Taiwan. The second part is developed from the combination of the paper by Brand and Blelloch (1973) and a typhoon forecasting handbook developed by Taiwan (1982). This part indicates the possible tracks tropical cyclones take crossing Taiwan and how to determine which track to forecast. Hopefully using this guide will help improve the forecasts of tropical cyclones crossing Taiwan.

PART 1 Intensity and speed changes associated with typhoons crossing Taiwan.

In 1973 Brand and Blelloch published a paper on the characteristic of typhoons crossing Taiwan. In this paper they examined typhoons from 1960-1972 crossing Taiwan from east to west. The average intensity and speed profile for typhoons from 48 hours prior to landfall to 12 hours after leaving Taiwan was one of items they looked at. However, only a limited number of typhoons were studied. I have updated Brand and Blelloch's study to included typhoons from 1973-1989 and for Typhoons back to 1945.

The study will be broken down into two sections. The first section looks at the mean speed profile for typhoons crossing Taiwan from 1945-1989. The second section looks at the intensity profile for typhoons crossing Taiwan from 1945-1989. In both cases I will compare the results to those found by Brand and Blelloch.

As mentioned before this study will used typhoons which hit Taiwan between 1945 and 1989. The typhoons used are shown at the end of this part of the paper. The monthly distribution of these typhoons are shown in Table 1.1. As shown in this table, July, August, and September are the months which almost all typhoons hit Taiwan. Twenty typhoons or 40 % hit Taiwan in September, with 46 typhoons or 92% hitting Taiwan between July and September.

X_1 : MONTH

Bar:	From: (≥)	To: (<)	Count:	Percent:	
1	1	2	0	0%	
2	2	3	0	0%	
3	3	4	0	0%	
4	4	5	0	0%	
5	5	6	1	2%	
6	6	7	2	4%	
7	7	8	13	26%	
8	8	9	13	26%	
9	9	10	20	40%	- Mode
10	10	11	0	0%	
11	11	12	1	2%	
12	12	13	0	0%	

Table 1.1

Brand and Blelloch (1973) looked at all typhoon which hit Taiwan during 1960-1972 and then stratified them for strong and weak typhoons. They defined a strong typhoon as one which averaged 100 knots or over in the 24 hours prior to hitting Taiwan. Weak typhoons were those which averaged less than 100 knots for the 24 hours prior to hitting Taiwan. I have stratified my data in the same way plus I have included figures show how the intensity and speed profile changes when stratified for initial speed and the month.

Mean Speed Profiles

Figure 1.1 shows the mean speed from 48 hour prior to landfall to 12 hours after the typhoon leaves Taiwan for all typhoon hitting Taiwan from 1945-1989. Where -48 HR indicates 48 hours prior to hitting in Taiwan, LF-A indicates hitting Taiwan, LF-L indicates leaving Taiwan, and +12 HR indicates 12 hours after leaving Taiwan.

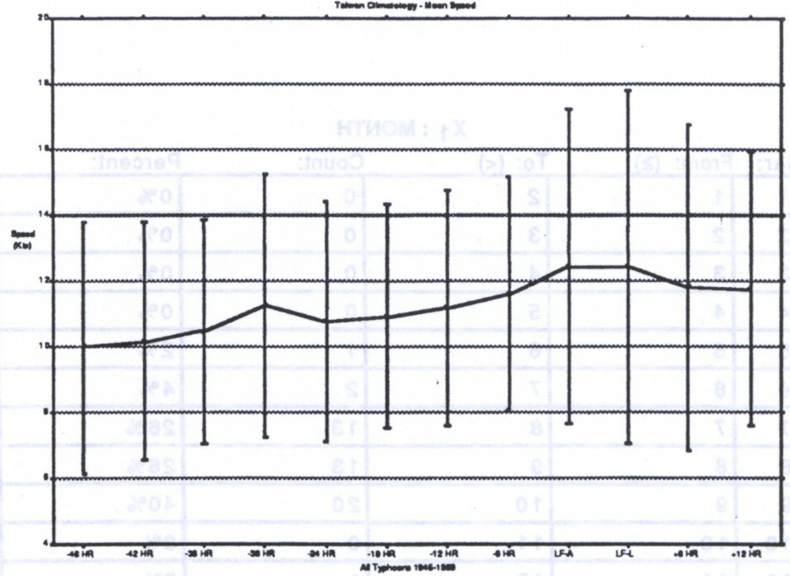


Figure 1.1

Figure 1.1 indicates that typhoons have a tendency to speed up from 10 to 12 knots as they track towards Taiwan. Once the typhoons leave Taiwan they have a tendency to slow down. However the standard deviation, indicated by the vertical bars, is fairly large in this figure and the figures to follow. This indicates there is a fairly large deviation in the speed of the typhoons looked at in this study. For this figure the standard deviation is 3 to 5 knots. This should be kept in mind as the results in this study are examined.

The speed profile for weak typhoons, Figure 1.2, has this same tendency of speeding up prior to hitting Taiwan and then slowing down. This is also indicated with strong typhoons , Figure 1.3. However weak typhoons don't slow down until after leaving Taiwan, while strong typhoons slow down when they hit Taiwan. With strong typhoons this acceleration is more gradual and there are indications that strong typhoons slow down more after they make landfall. The speed profiles for both the weak and strong typhoons also indicate slight acceleration somewhere between 42 to 30 hours prior to hitting Taiwan followed by a slight slowing down. The significance of this, if any, is not know at this time.

How do these results compare to those found by Brand and Blelloch? In their study the average speed of movement profile for all typhoons showed an increase in speed during the period from -48 to -24 hours and then a leveling off in speed just prior to a slight acceleration near Taiwan. The average speed ranged from 9 knots 48 hour before landfall to a little over 11 knots at landfall. Their study also indicated strong typhoons are faster moving than weak typhoons but weak typhoons seem more

effected by Taiwan. Their results indicate a marked increase in speed as weak typhoons cross the island. In comparison, the results for typhoons from 1945-1989 do indicate some difference in the speed of strong and weak typhoon, perhaps 1 knot. However this study indicates weak typhoons start to accelerate sooner, 12 prior to hitting Taiwan. In both studies, strong typhoon slow down as they cross Taiwan. Remember the standard deviation is fairly large and the database is still rather small, only 50 storms. So, in a general sense, the results found in this study and the one by Brand and Blelloch seem basically the same.

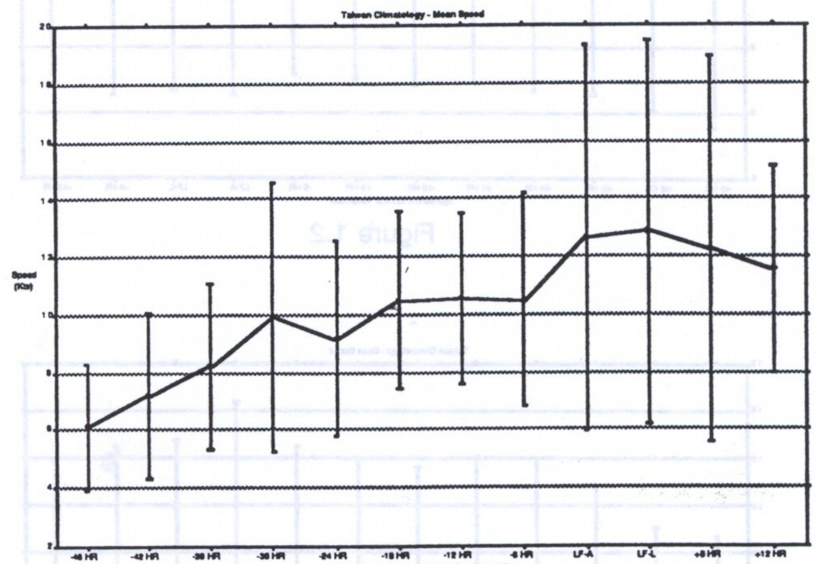


Figure 1.4

Next the speed profiles for fast and slow typhoons are examined. Fast typhoons are defined as typhoons moving faster then the mean speed of 10 knots at 48 hours prior to hitting Taiwan. Slow typhoons move slower than 10 knots at 48 hours prior to hitting Taiwan. Figures 1.4-1.6 show the speed profiles for slow typhoons while figures 1.7-1.9 show the speed profiles for fast typhoons. For slow typhoons, Figure 1.4, there is a significant acceleration from 48 hours prior to hitting Taiwan to landfall. Slow typhoons accelerate from 6 to 13 knots with significant acceleration from 48 to 30 hour prior to hitting Taiwan and from 6 hours prior to landfall. Weak typhoons which are slow, Figure 1.5, also accelerate as they head for Taiwan with significant acceleration from 6

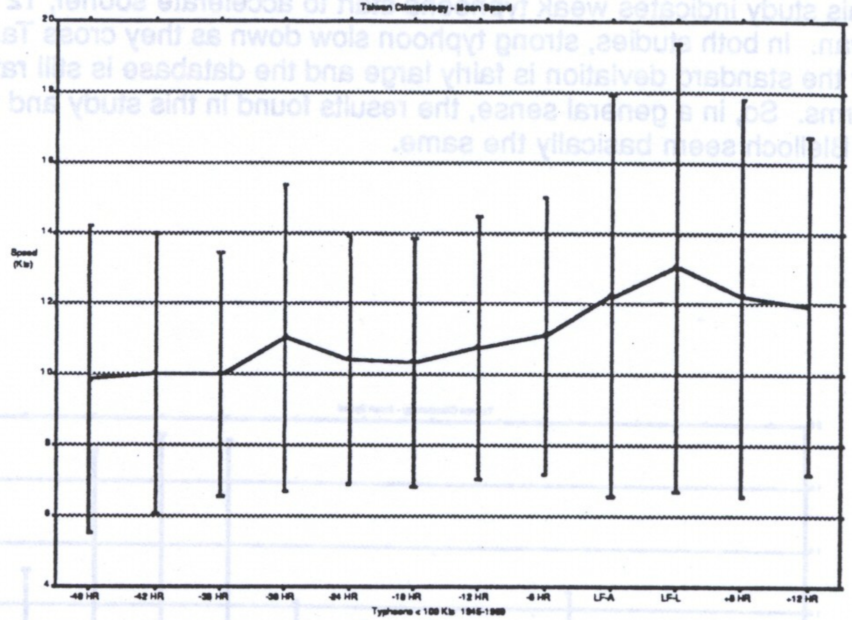


Figure 1.2

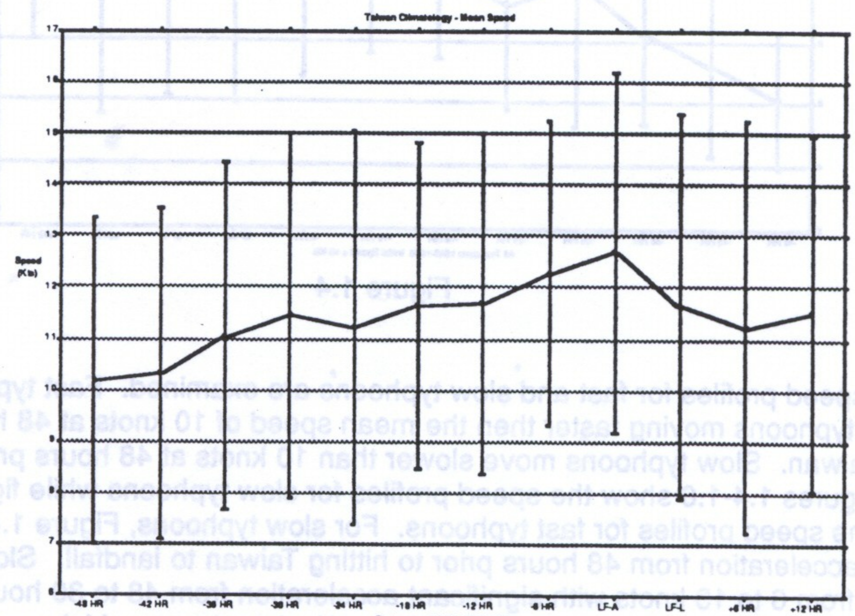


Figure 1.3

hours prior to after crossing Taiwan. The weak typhoons then slow down after they leave Taiwan. The strong typhoons with the initial slow speed also accelerate, but not as much as weak typhoons, Figure 1.6. The strong typhoons slow

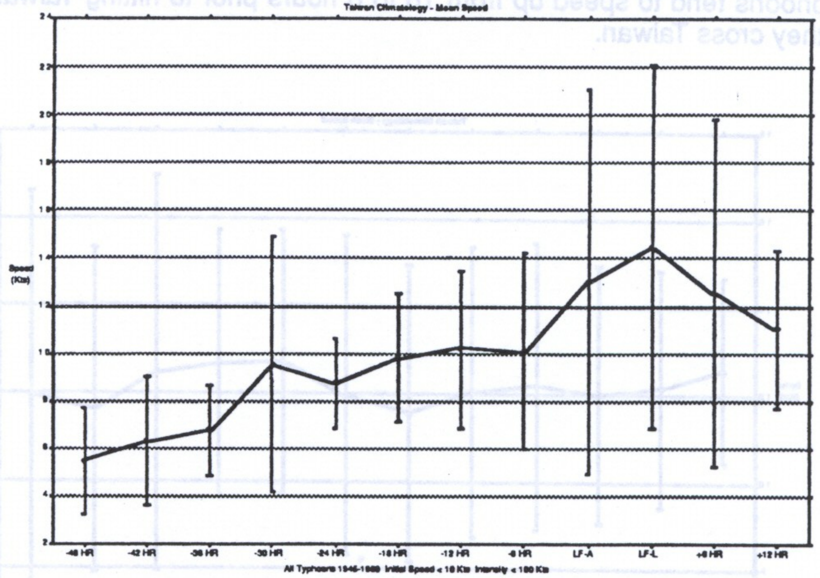


Figure 1.5

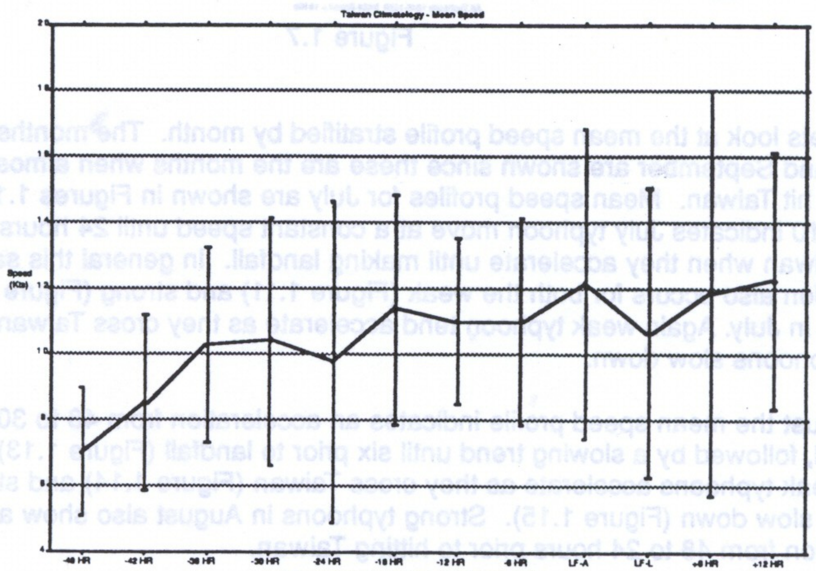


Figure 1.6

down as they cross Taiwan and start to speed up again after leaving Taiwan.

For fast typhoons, initial speed greater than 10 knots, there is little change in the speed for all typhoons (Figure 1.7) and for weak typhoon (Figure 1.8). However, strong typhoons tend to speed up from 18 to 6 hours prior to hitting Taiwan, and slow down as they cross Taiwan.

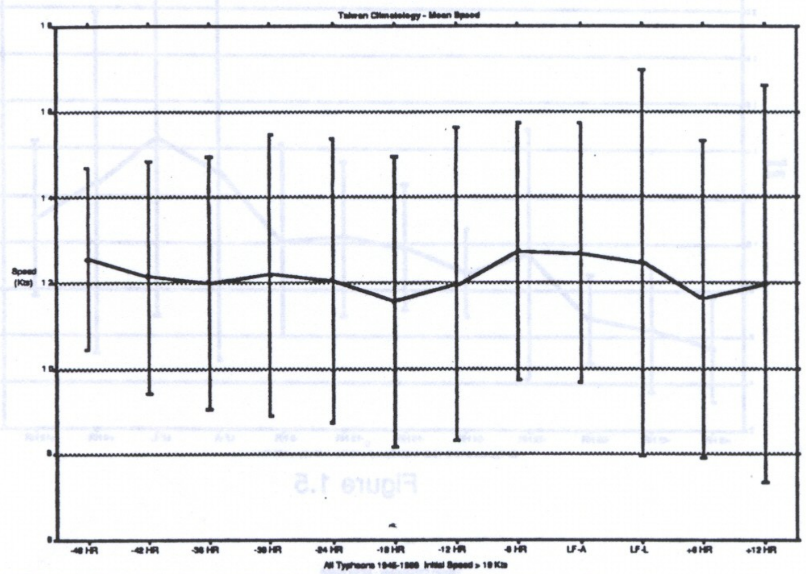


Figure 1.7

Finally lets look at the mean speed profile stratified by month. The months of July, August, and September are shown since these are the months when almost all the typhoons hit Taiwan. Mean speed profiles for July are shown in Figures 1.10-1.12. Figure 1.10 indicates July typhoon move at a constant speed until 24 hours prior to hitting Taiwan when they accelerate until making landfall. In general this same acceleration also occurs for both the weak (Figure 1.11) and strong (Figure 1.12) typhoons in July. Again weak typhoon tend accelerate as they cross Taiwan, while strong typhoons slow down.

For August the mean speed profile indicates an acceleration from 48 to 30 hours prior to landfall, followed by a slowing trend until six prior to landfall (Figure 1.13). As before weak typhoons accelerate as they cross Taiwan (Figure 1.14) and strong typhoons slow down (Figure 1.15). Strong typhoons in August also show a significant acceleration from 48 to 24 hours prior to hitting Taiwan.

The September mean speed profile indicates slow acceleration until landfall with a

small peak in speed at 30 hours prior to landfall. Both weak and strong September

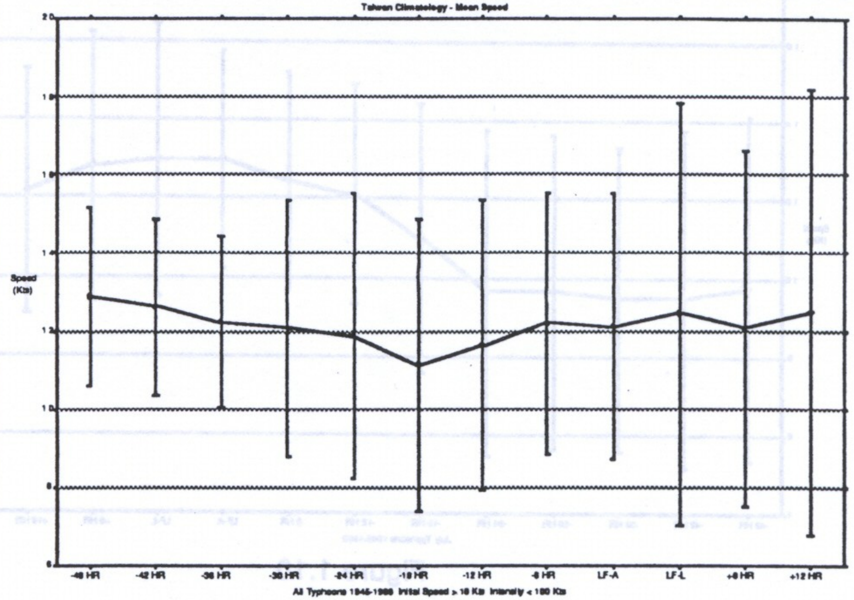
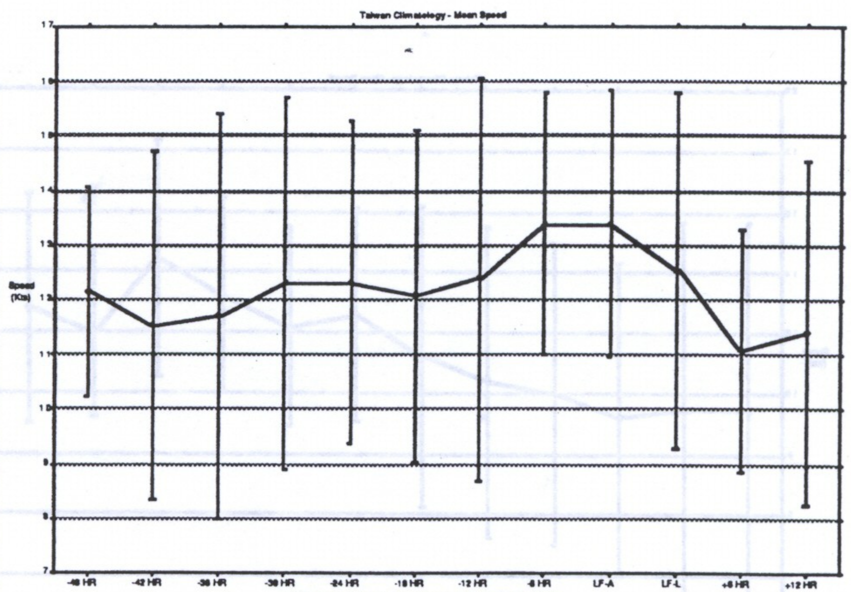


Figure 1.8



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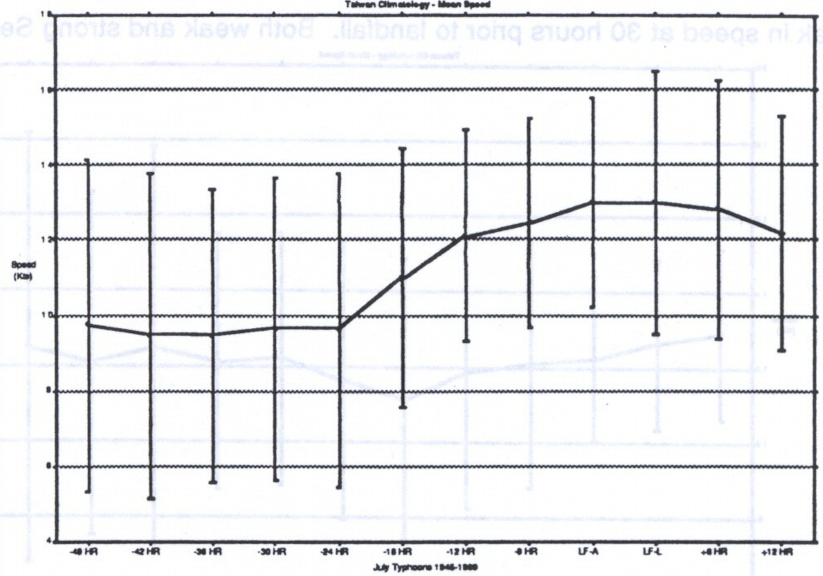

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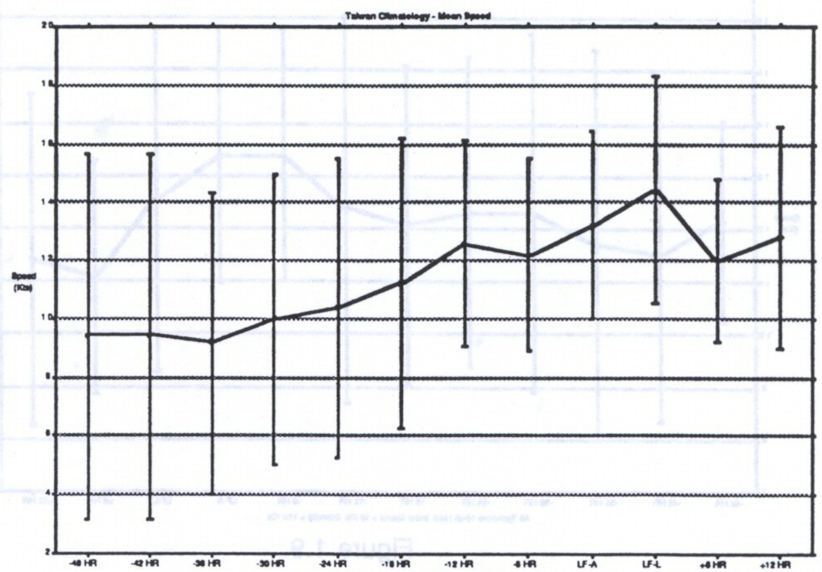
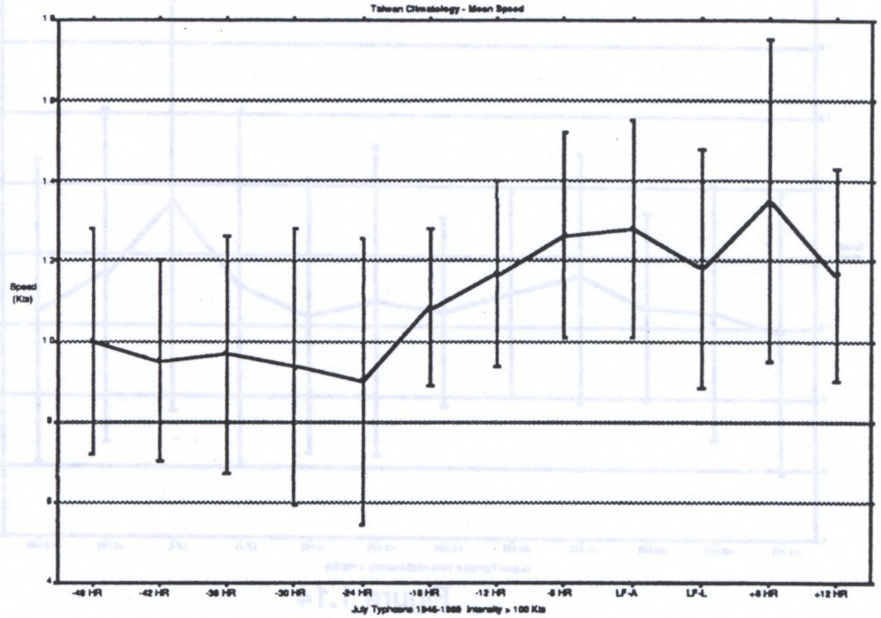


Figure 1.11



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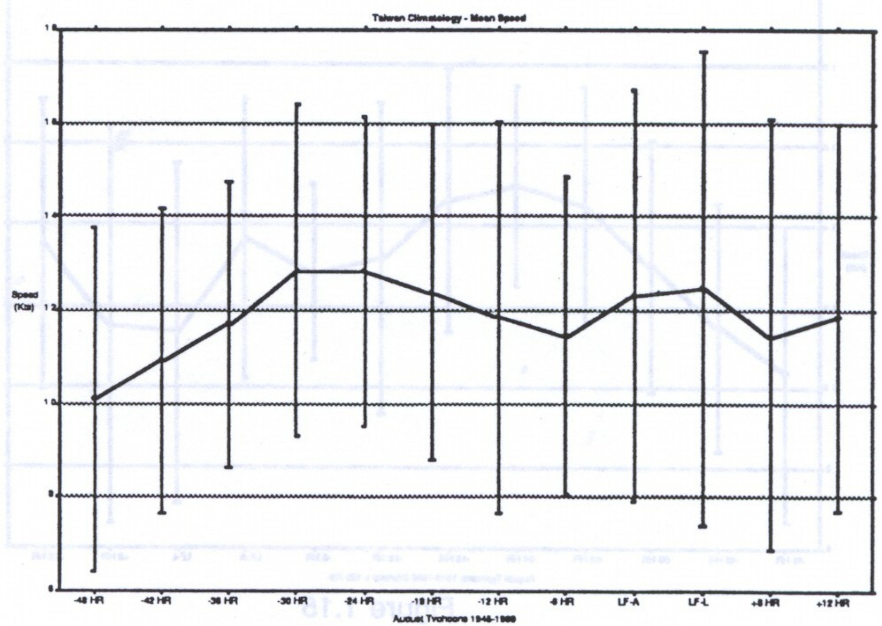

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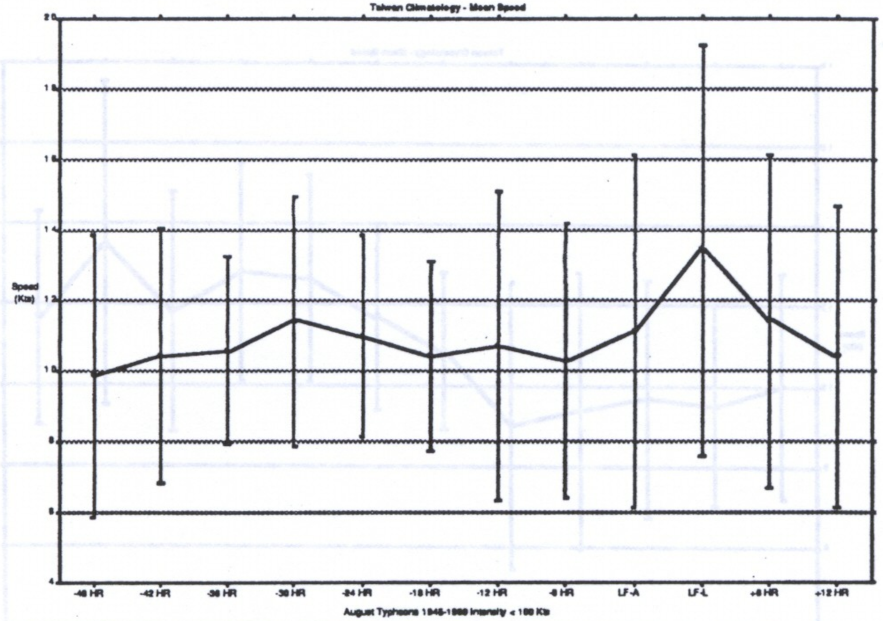

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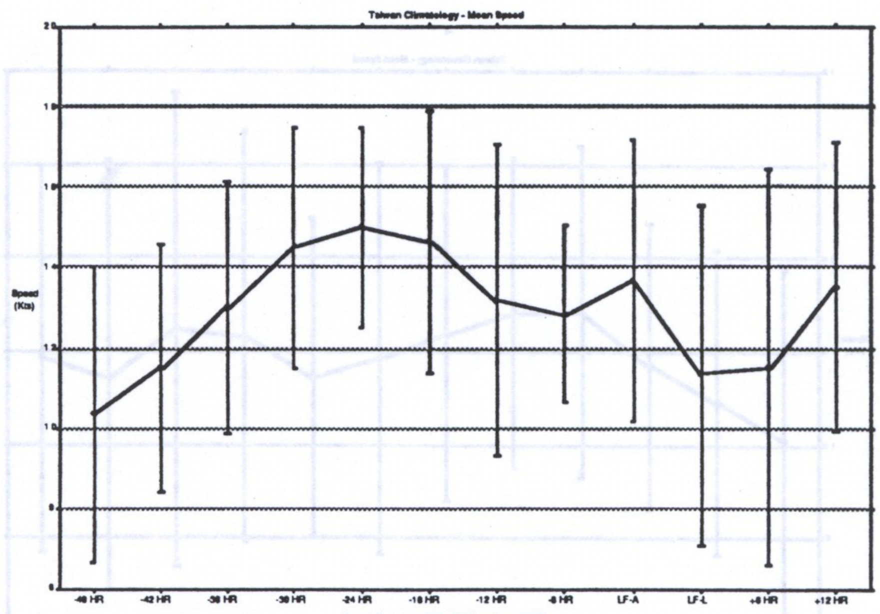

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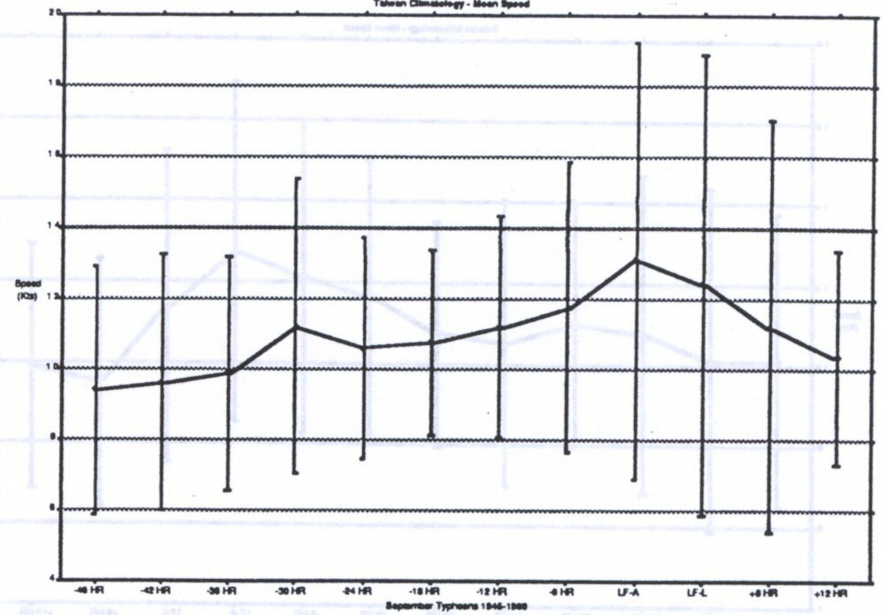

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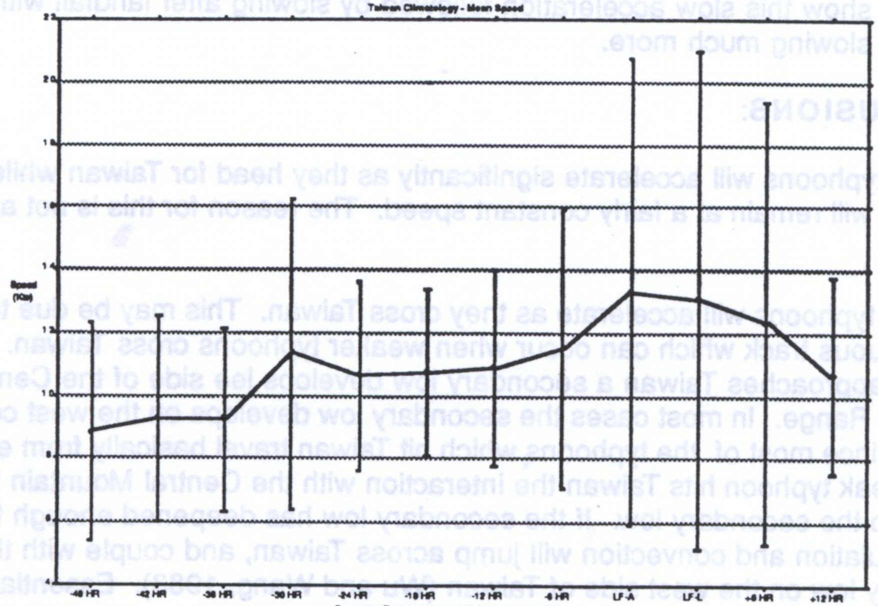

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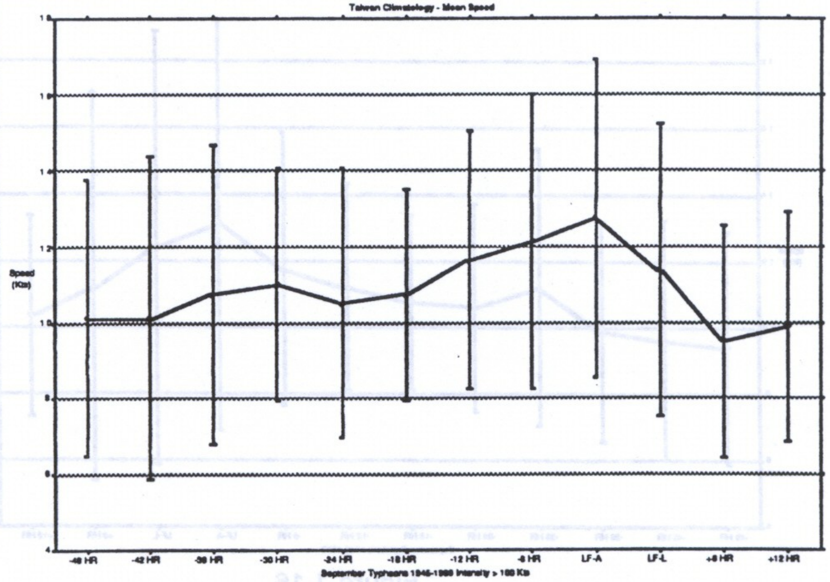


Figure 1.18

typhoons show this slow acceleration followed by slowing after landfall with strong typhoons slowing much more.

CONCLUSIONS:

1. Slow typhoons will accelerate significantly as they head for Taiwan while fast typhoons will remain at a fairly constant speed. The reason for this is not apparent at this time.

2. Weak typhoons will accelerate as they cross Taiwan. This may be due to discontinuous track which can occur when weaker typhoons cross Taiwan. As the typhoon approaches Taiwan a secondary low develops lee side of the Central Mountain Range. In most cases the secondary low develops on the west coast of Taiwan, since most of the typhoons which hit Taiwan travel basically from east to west. As the weak typhoon hits Taiwan the interaction with the Central Mountain Range help to spin up the secondary low. If the secondary low has deepened enough the upper-level circulation and convection will jump across Taiwan, and couple with the secondary low on the west side of Taiwan (Wu and Wang, 1983). Essentially the momentum is transferred to the secondary low and this becomes the typhoon. Because of the discontinuous track the typhoon appears to have accelerated as it crosses Taiwan. This conclusion is supported by Figures 1.5 and 1.8. For weak typhoons which are slow (Figure 1.5) there is significant acceleration as the typhoons crosses Taiwan. Since the typhoons are slow the secondary low has more time to

deepen which indicates a better chance of a discontinuous track. For fast, weak storms (Figure 1.8) there is no significant change in the speed because the secondary low did not have time to develop enough for a discontinuous track to occur.

3. Strong typhoons slow down as they cross Taiwan. In cases when strong typhoons hit Taiwan secondary lows develop, but they are not deep enough to become significant (Wu and Wang, 1983). The strong typhoons hit Taiwan and are slowed down by the Central Mountain Range.

Mean Intensity Profiles

The second part of this study examines the mean intensity profile for typhoon hitting Taiwan from 48 hours prior to landfall to 12 hours after leaving Taiwan. For all typhoons (Figure 1.19) intensification occurs until 12 hours prior to landfall with the typhoons weakening rapidly after that due to land interaction with Taiwan. This same mean intensity profile occurs for both weak and strong typhoons also, Figures 1.20 and 1.21, respectively. As with the mean speed profiles, the mean intensity profiles also have a fairly large standard deviation. Now, lets compare this with the study done by Brand and Blelloch. Their study indicated an increase in intensity during the period 48 to 24 hours prior to hitting Taiwan. The intensity then levels off until 12 hours prior to landfall before decreasing as the typhoons cross Taiwan. Both Brand and Blelloch's study and this one indicate the same basic mean intensity profile, however this study does indicate continued slow intensification until 12 prior to landfall.

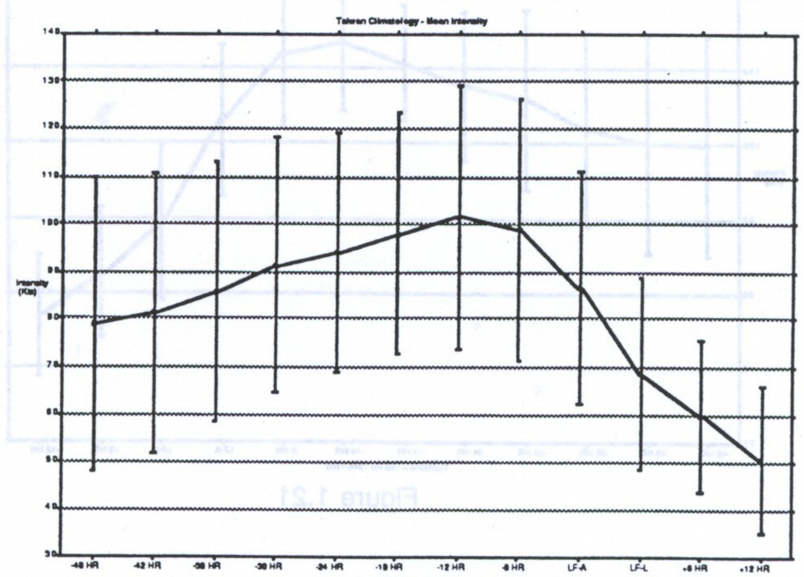
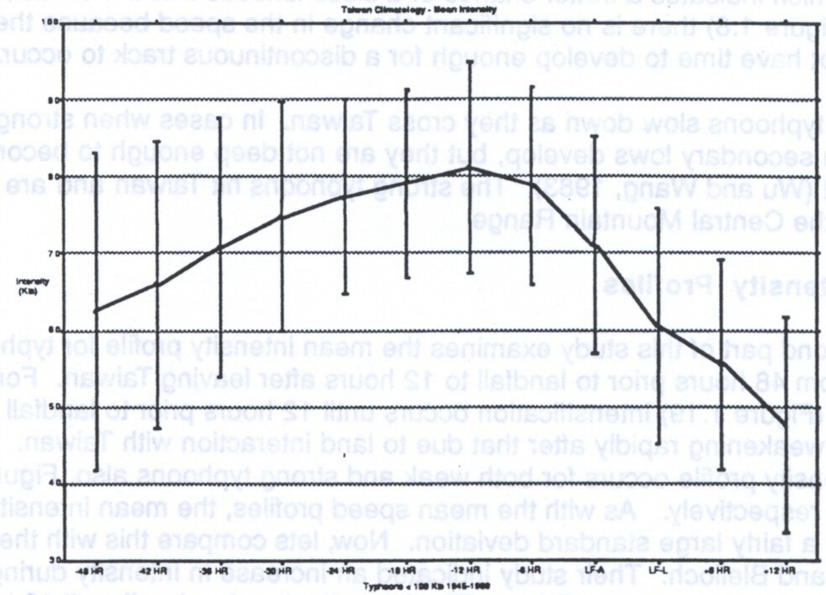


Figure 1.19



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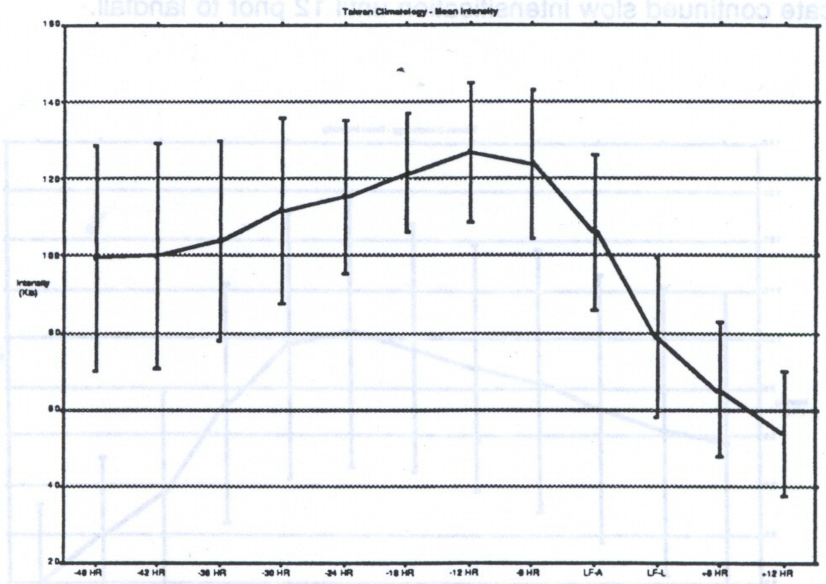
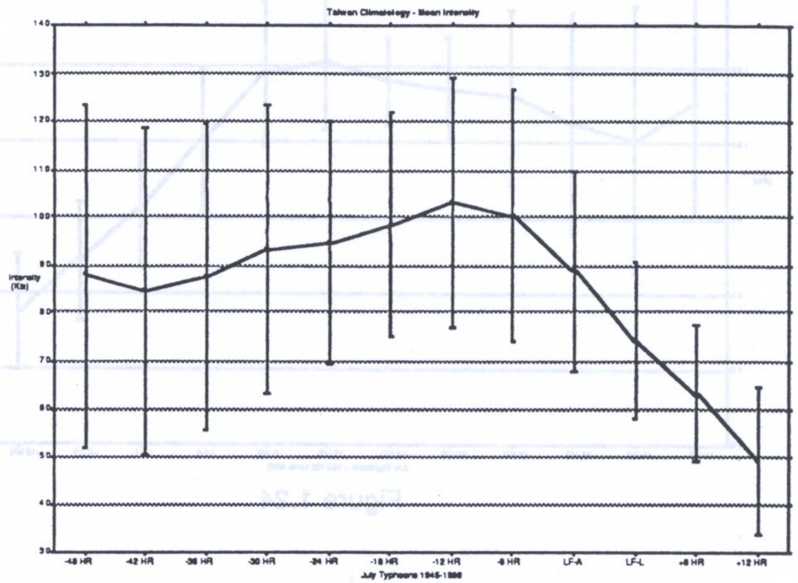


Figure 1.21

When the mean intensity profile is stratified by month (July, August, and September)

there is no significant change in the mean intensity profile, see Figures 1.22-1.30. The most intense typhoon appear to be in August (Figure 1.27) with a mean maximum intensity of 140 knots compared to 120 knots for July and September.



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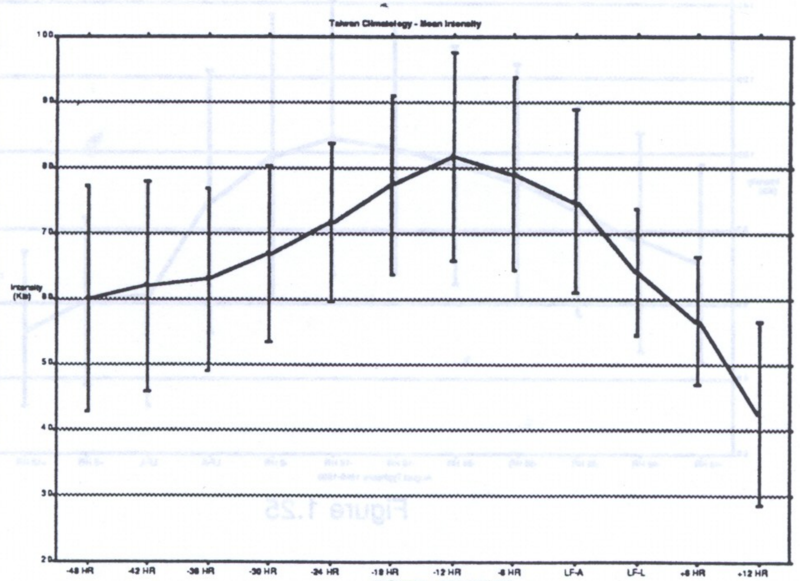

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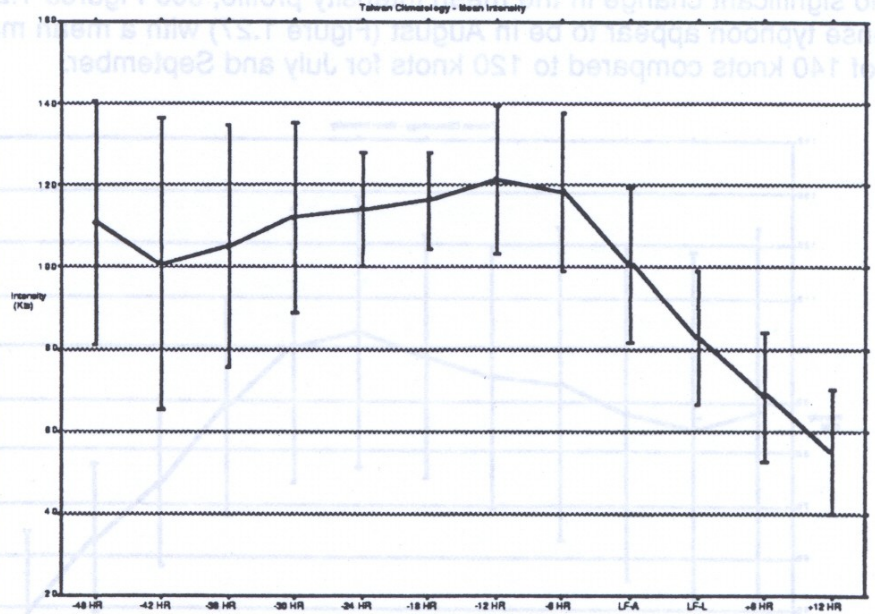

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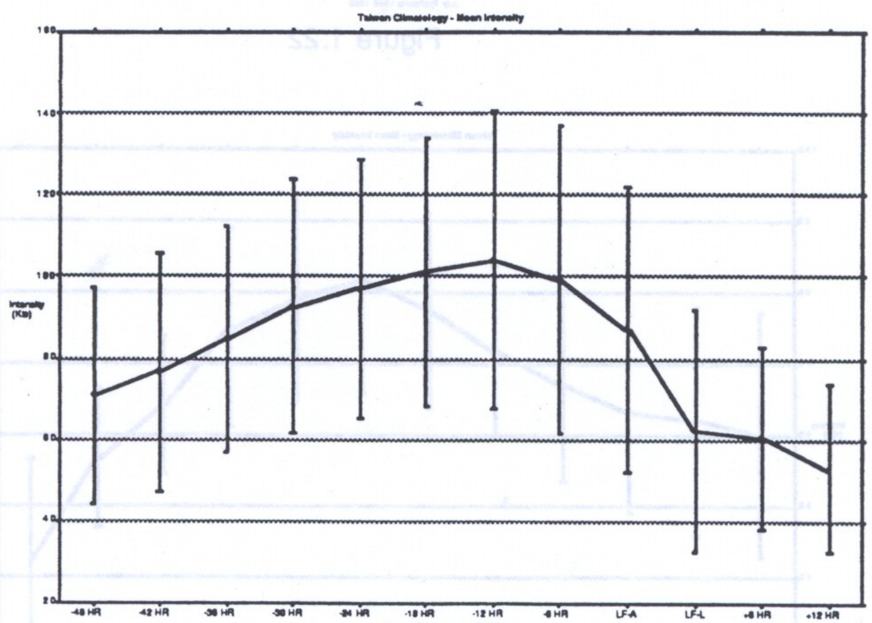

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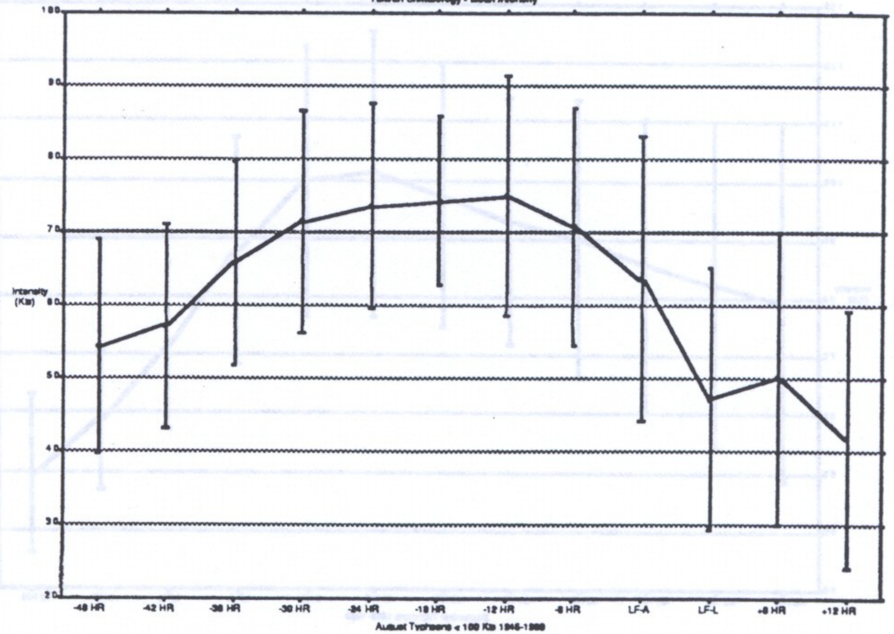

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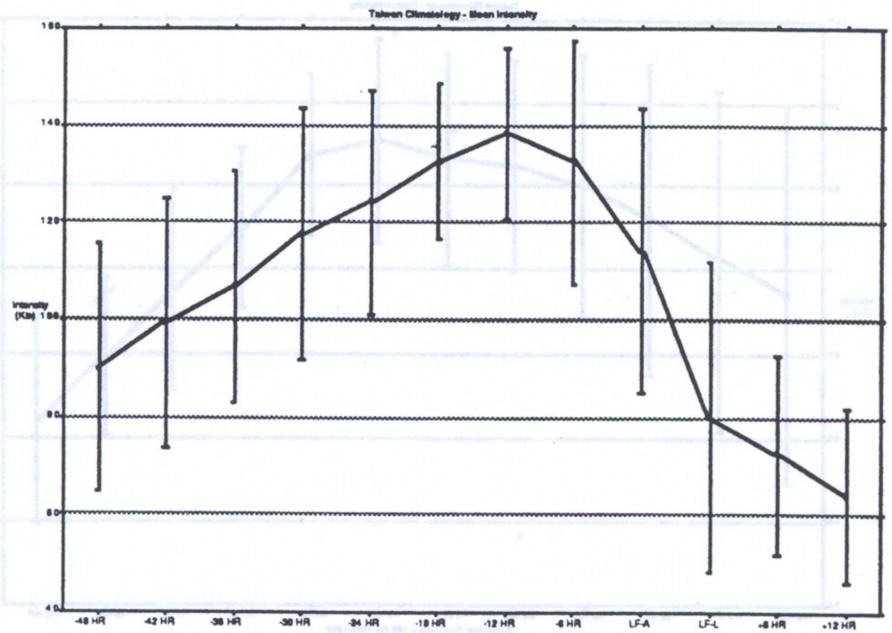
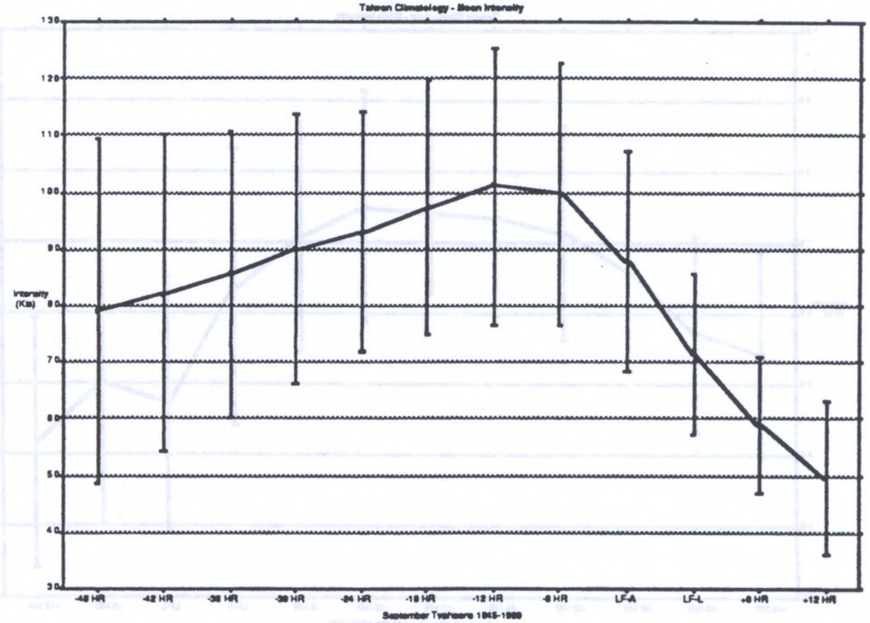


Figure 1.27



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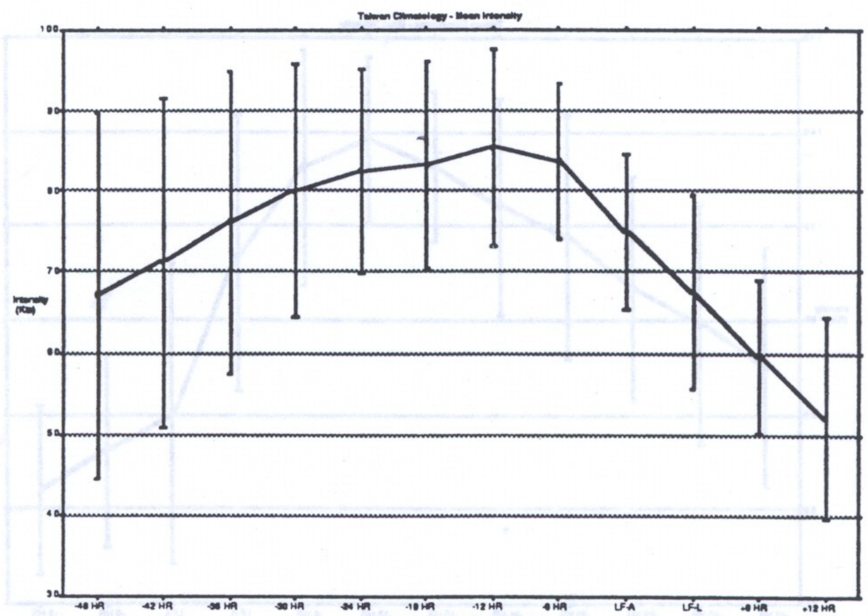

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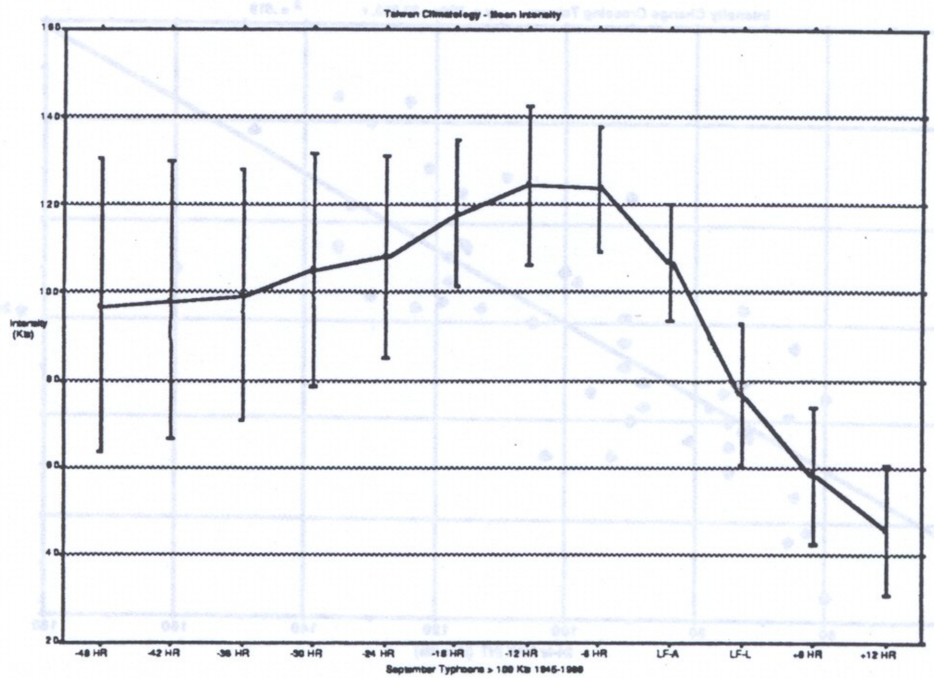


Figure 1.30

The average 24 hour intensity prior to hitting Taiwan (I1) versus the change in intensity (I1-I2), where I2 is the intensity 6 hours after leaving Taiwan is shown in Figure 1.31. This indicates how much a typhoon will weaken as in crosses Taiwan. The change in intensity found in this study is the similar to what Brand and Blelloch found in their study. Figure 1.32 show the same kind of comparison but uses the intensity 12 hours prior to landfall (I3) versus the change intensity (I3-I4), where I4 is the intensity
6 hours after leaving Taiwan.

CONCLUSIONS:

1. Typhoons will slowly intensify as they head for Taiwan, reaching peak intensity 12 hours prior to landfall.

2. Within 12 hours of landfall typhoons will start to weaken rapidly due to land interaction with Taiwan.

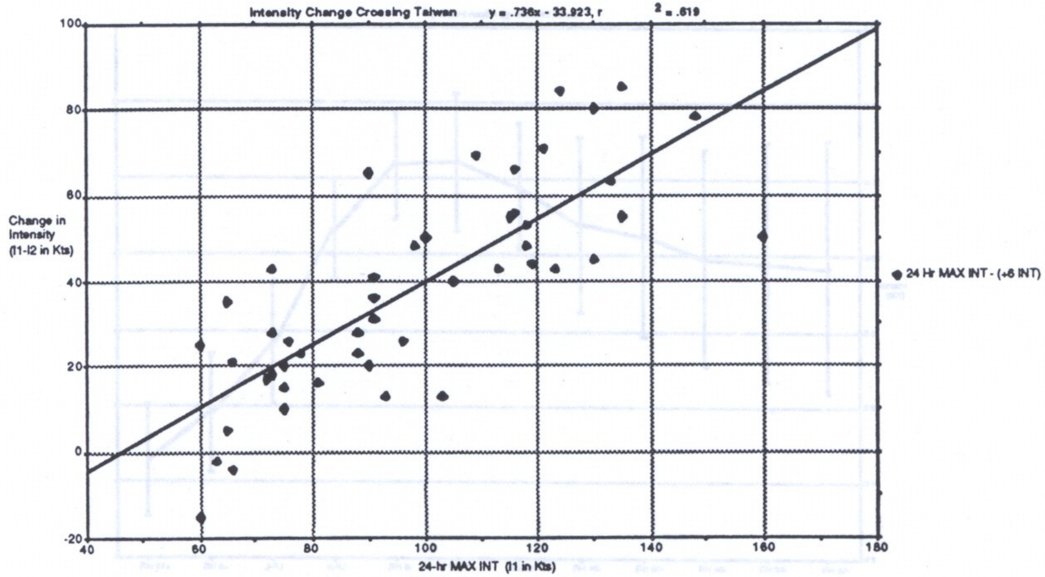


Figure 1.31

I1 - Average 24 hour intensity prior to hitting Taiwan
I2 - Intensity 6 hours after leaving Taiwan
(I1-I2) - Change in intensity

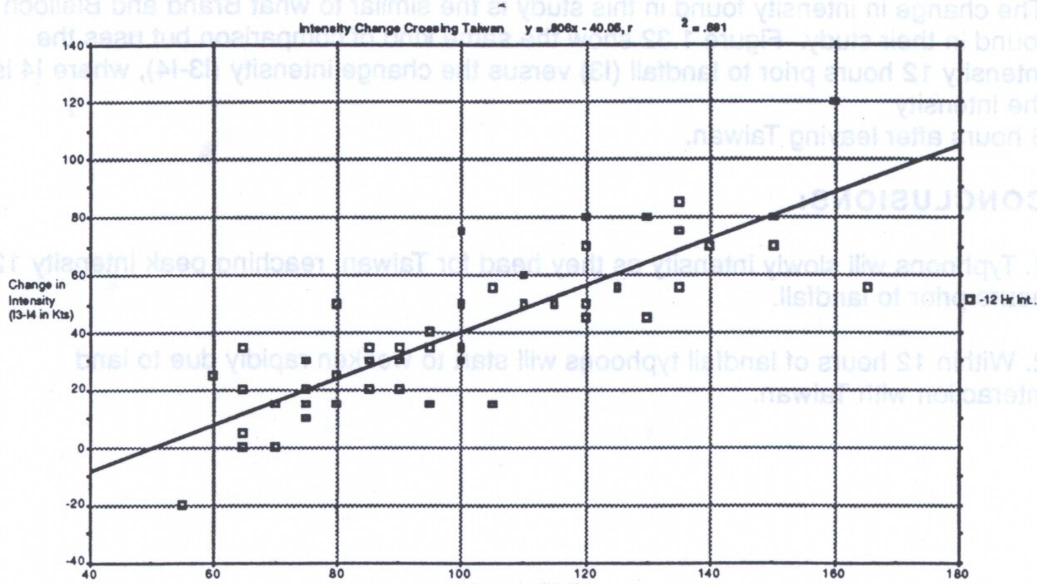


Figure 1.32

I3 - Intensity 12 hours prior to hitting Taiwan
I4 - Intensity 6 hours after leaving Taiwan
(I3-I4) - Change in intensity

	NWP - NWP - YR	NWP - NWP - NAME	NWP - NWP - MO
1	45	HELEN	9
2	45	URSULA	9
3	46	QUERIDA	9
4	47	INEZ	8
5	47	NANETTE	10
6	48	JACKIE	9
7	49	NELLY	9
8	53	KIT	7
9	53	PHYLLIS	8
10	56	DINAH	9
11	56	FREDA	9
12	56	GILDA	9
13	58	WINNIE	7
14	59	JOAN	8
15	59	LOUISE	9
16	60	SHIRLEY	7
17	60	TRIX	8
18	60	ELAINE	8
19	61	BETTY	5
20	61	ELSIE	7
21	61	LORNA	8
22	61	JUNE	8
23	62	PAMELA	9
24	62	SALLY	9
25	62	KATE	7
26	62	OPEL	8
27	62	AMY	9
28	63	WENDY	7
29	65	HARRIET	7
30	65	MARY	8
31	67	CLARA	7
32	67	NORA	8
33	67	GILDA	11
34	69	ELSIE	9
35	71	NADINE	7
36	71	AGNES	9
37	71	BESS	9
38	75	NINA	8
39	75	BETTY	9
40	76	BILLIE	8

	NWP - NWP - YR	NWP - NWP - NAME	NWP - NWP - MO
41	77	VERA	7
42	80	NORRIS	8
43	80	PERCY	9
44	81	JUNE	6
45	82	ANDY	7
46	82	DOT	8
47	84	ALEX	7
48	86	NANCY	6
49	86	ABBY	9
50	87	ALEX	7
51	89	SARAH	9

PART 2 Tracks associated with tropical cyclones crossing Taiwan.

Part 2 is a guide on the possible tracks tropical cyclones take crossing or nearly crossing Taiwan. This consists of excerpts from two papers. The first is the tropical cyclone forecasting handbook developed in Taiwan (Methods of Typhoon Forecasting in Taiwan, Republic of China, 1982). This handbook has a section to help predict the track of typhoons crossing Taiwan. Predictors, such as, the storm's heading, the angle of the approach flow, the intensity, and the location of landfall are used to determine the track of the tropical cyclone. The second paper is by Brand and Blelloch, 1973. This paper breaks the tropical cyclones crossing Taiwan into categories which depend on the tropical cyclones intensity, or vertical extent. Then they indicate some forecasting rules to determine the tropical cyclone's track. The following are excerpts from these papers to help the Typhoon Duty Officers forecast the tropical cyclones crossing Taiwan.

The first excerpt is from the handbook developed in Taiwan. As mentioned before, track of the tropical cyclone depends on several predictors; the storm's heading, the angle of the approach flow, the intensity, and the location of landfall. The tracks are separated into two categories. The first is storms moving across the Central Mountain Range. The second is is storms moving northward, parallel to the Central Mountain Range. The storms are further separated by the type of storm, continuous or discontinuous. Finally the predictors are used to determine the possible tracks of the storms.

- Categories of Storms

A. Moves across Central Mountain Range (CMR)

- Types of Storms
  - -- Continuous Track (Type 1)
  - -- Discontinuous Track (Type 2)

- Predictors of Tracks
  - -- α is the storm's heading
  - -- β the angle of the approach flow (look at the wind direction at Peng Chia Hsu (46695) at 25.6N 122.1E or at stations on the northern tip of Taiwan)
  - -- Intensity
  - -- Location of landfall

- Track forecast
  - -- Continuous track (Type 1)
    - --- 290 deg < α < 320 deg
    - --- 20 deg < β < 60 deg

--- Intensity > 50 kts

-- Discontinuous track (Type 2)

--- 320 deg < α < 360 deg

--- 60 deg < β < 190 deg

- See Table 2.1 and Fig. 2.1 for determining the possible track or tracks

B. Storms moving northward parallel to CMR

- Types of storms
  -- Continuous track (Type 1)
  -- Discontinuous track (Type 2)

- Storm's center greater than 30 n mi. from CMR
  -- Continuous track (Type 1)

- Storm's center less than 30 n mi. from CMR
  -- Discontinuous track (Type 2)

- See Table 2.2 and Fig. 2.1 for determining the possible track or tracks

Table 2.1 Guide to typhoon track forecasting in the area of Taiwan

General Classes

A. Typhoons moving across the CMR with a continuous track

1. Predictors of typhoon track

a.

1) 290 deg < α < 320 deg

2) 20 deg < β < 60 deg

3) The maximum sustained surface winds are > 50 kts

-- Possible type of tracks, refer to pictures (a) - (c) in Fig. 2.1

-- Description of the track - Passing across the CMR freely

b.

1) 280 deg < α < 310 deg

2) 20 deg < β < 60 deg

3) The maximum sustained surface winds are > 50 kts

4) Landing location between 23N and 23.5N

-- Possible type of track, refer to picture (e) in Fig. 2.1

-- Description of the track - Looping on the east side the CMR

c.

1) 290 deg < α < 320 deg

2) 20 deg < β < 60 deg

3) The maximum sustained surface winds are > 50 kts
4) Landing location between 23N and 23.5N
-- Possible type of track, refer to picture (f) in Fig. 2.1
-- Description of the track - The upper portion of the typhoon passes over the CMR, while its lower portion remains on the east side of the CMR

B. Typhoon moving across the CMR with a discontinuous track
1. Predictors of typhoon track
a.
1) 320 deg < α < 360 deg
2) 60 deg < β < 190 deg
3) Landing location between 22.5N and 24N
4) The wind at Peng Chia Hsu is 20 kts or more
-- Possible type of tracks, refer to pictures (g) - (h) in Fig. 2.1
-- Description of the track - The induced low, developing to the northwest of the center's landing position, on the west side of the CMR replaces the original typhoon
b.
1) 320 deg < α < 360 deg
2) 60 deg < β < 180 deg
3) Landing location is north of 24N
4) The wind at Peng Chia Hsu is 20 kts or more
-- Possible type of tracks, refer to pictures (i) - (j) in Fig. 2.1
-- Description of the track - The induced low, developing to the southwest of the center's landing position, on the west side of the CMR replaces the original typhoon
c.
1) 280 deg < α < 360 deg
2) 60 deg < β < 190 deg
3) Landing location is south of 22.5N
4) The wind at Peng Chia Hsu is 20 kts or more
-- Possible type of track, refer to picture (k) in Fig. 2.1
-- Description of the track - The induced low on the west side of the CMR intensifies to be a typhoon, while the original one passes across the CMR and eventually dissipates

<u>Table 2.1 Guide for forecasting typhoon motion parallel to the CMR</u>

Predictors of typhoon track
1) The distance from the typhoon's center to the CMR is over about 30 n mi. (types C1, D1, E1, F1)
2) The distance from the typhoon's center to the CMR is within 30 n mi. (types C2, D2, E2, F2)

General Classes

A. Typhoon moving northward to the east of the CMR
   1. Type C1, picture (m) in Fig. 2.1
      -- Description of the track - Typhoon with a continuous track
   2. Type C2, picture (l) in Fig. 2.1
      -- Description of the track - Typhoon with a discontinuous track

B. Typhoon moving northward to the west of the CMR
   1. Type D1, picture (q) in Fig. 2.1
      -- Description of the track - Typhoon with a continuous track
   2. Type D2, pictures (n) - (p) in Fig. 2.1
      -- Description of the track - Typhoon with a discontinuous track

C. Typhoon passing over the area north of the CMR
   1. Type E1
      -- Description of the track - The CMR has no influence on the typhoon track
   2. Type E2, pictures (r) - (s) in Fig. 2.1
      -- Description of the track - The typhoon makes a detour around the northern tip of the CMR

D. Typhoon passing over the are south of the CMR
   1. Type F1, picture (o) in Fig. 2.1
      -- Description of the track - The CMR has no influence on the typhoon track
   2. Type F2, pictures (t) - (u) in Fig. 2.1
      -- Description of the track - The typhoon makes a detour around the southern tip of the CMR

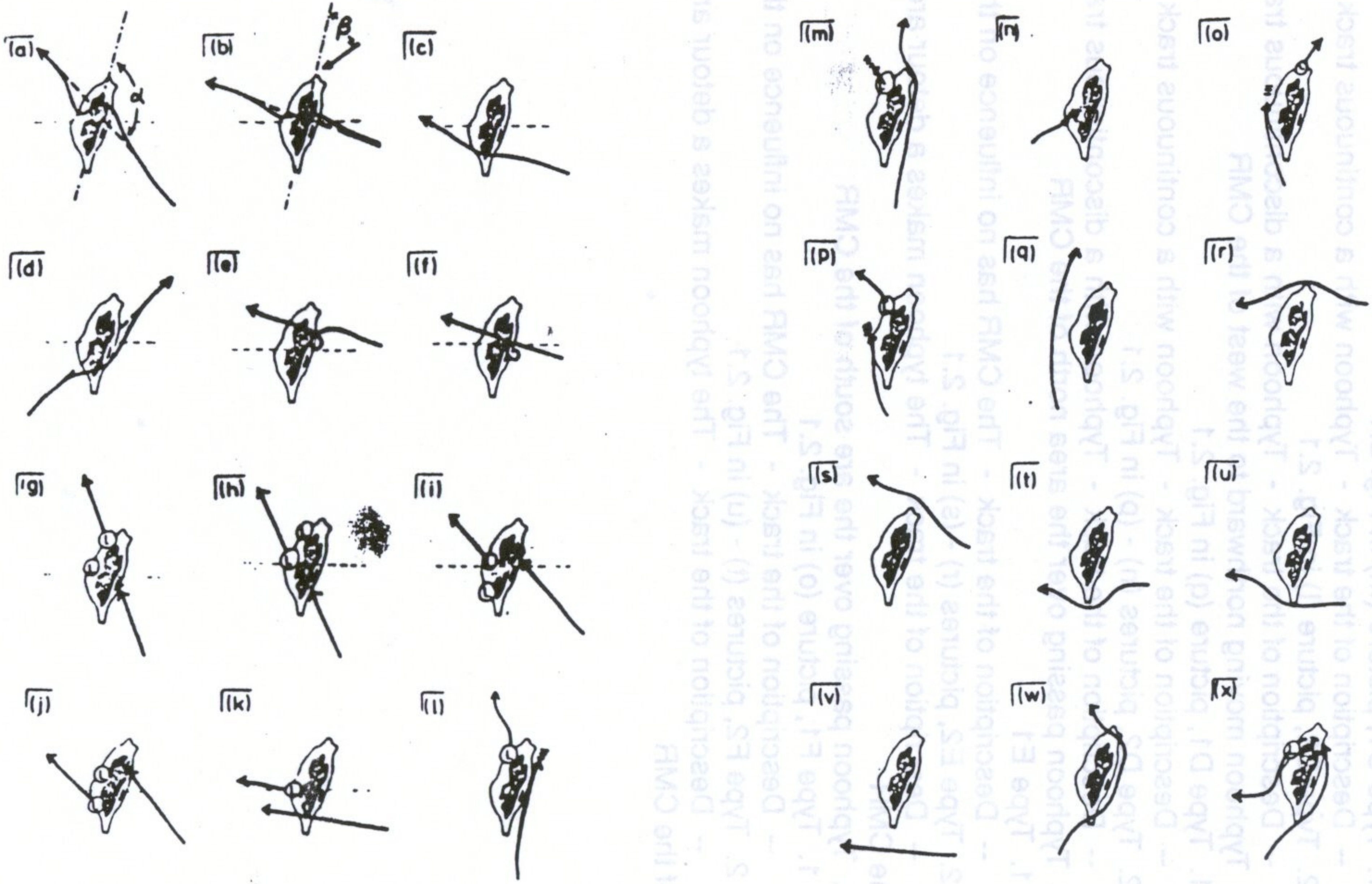


Fig. 21 Patterns of typhoon tracks in the area of Taiwan

In Brand and Blelloch's paper tropical cyclones crossing Taiwan are separated into three categories which depend on intensity or the approximate vertical extent of the tropical cyclone. Category I tropical cyclone have a maximum intensity of less than 50 kts or less than 10,000 ft vertical extent. These tropical cyclones will tend to dissipate over the island. Tropical cyclones with an intensity between 50 and 100 kts, or a vertical extent around 20,000 ft are Category II. Category II tropical cyclones will tend to produce secondary lows that may take over as the dominate circulation. These are the tropical cyclones which appear to jump or accelerate across the island. Tropical cyclone with an intensity of greater than 100 kts, or a vertical extent of greater than 35,000 ft are Category III. These tropical cyclones will follow a continuous track even though a secondary low may form. The forecast rules developed by Brand and Blelloch are shown in the next few pages.

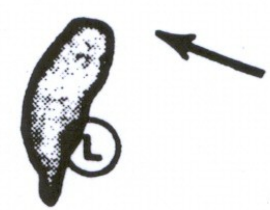
a. If a typhoon heads westerly or northwesterly toward Taiwan and a secondary low forms on the western side of the island (near Taichung -24°09'N, 120°41'E) and intensifies, the typhoon will not recurve.

b. If a typhoon heads westerly or northwesterly toward the southern tip of Taiwan or just south of the island and a series of secondary lows or a trough forms on the western side of the island, there will be little or no recurvature.

b.

c. If a typhoon heads westerly or northwesterly toward the northern tip of Taiwan and a secondary low forms near the southeast edge of the island (near Taitung-22°45'N, 121°09'E), the typhoon will pass north, or just hit the northern tip of the island.

c.



d. If a typhoon heads northwesterly toward Taiwan in a northerly curving trajectory (or a typhoon heads north in close proximity to the east coast of Taiwan), and a secondary low appears on the west coast of Taiwan and moves slowly northward and weakens, the typhoon will not cross Taiwan.* These typhoons would in general be the more intense typhoons (Category III).

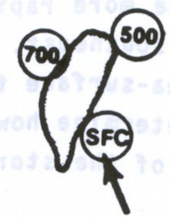
d.

e. If a typhoon heads northwesterly toward Taiwan in a northerly curving trajectory (or a typhoon heads north in close proximity to the east coast of Taiwan), and a secondary low appears on the west coast of Taiwan and intensifies, the secondary low will take over the typhoon circulation.** These typhoons would in general be the less intense typhoons (Category II).

e.

f. If a typhoon is heading north-northwesterly toward Taiwan and the vertical axis tilt of the cyclonic circulation breaks into two segments (the lower to the northwest and the upper to the northeast), the typhoon is in the process of recurvature. If a constant vertical tilt exists, the typhoon will head in that direction.

f.



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*These secondary lows can at times extend up to 10,000 ft, and this could mislead the forecaster in thinking the typhoon has crossed the island.

**The closer to the mountain range the primary typhoon lies, the better are the chances for a secondary low to take over the circulation.

g. If a typhoon is heading northerly toward the southern tip of Taiwan, the typhoon will tend to move toward the east side of the island.

g.

The synoptics of each individual situation should also be taken into consideration. For example, if a tropical cyclone is approaching or crossing Taiwan in the late typhoon season, and this coincides with an early surge of the northeast monsoon, cool air may enter the circulation of the storm with a resulting decrease in intensity. However, a surge may only increase the low-level cyclonic shear in the region of the trough, if present, and this will present an excellent path for the storm.

In the later months of the typhoon season the ocean becomes a factor since sea-surface temperatures near Taiwan decrease more rapidly than those in the Philippine Sea region to the southeast. The thermal structure parameters, other than sea-surface temperature, are also very important in that they determine how much warm water is available for the energy of the storm (Brand, 1971).

Hopefully, the speed and intensity climatology, the possible tropical cyclone tracks, and the forecast rules presented in this guide will help with forecast the motion, speed, and intensity of tropical cyclone which cross over or are affected by Taiwan.

References:

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